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MDPI

Dielectronic and Radiative Recombination of Pm-like Tungsten (W XIV): A Relativistic Benchmark for Kilonova Modelling

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KILONOVAE and r-PROCESS

Neutron star mergers are considered prime sites for r-process nucleosynthesis, creating heavy nuclei like lanthanides and actinides [1]. Validating this hypothesis relies on analyzing their electromagnetic transient, the **kilonova**.

After 5 days, the ejecta enters NLTE conditions: **ionization balance** and **level populations** are no longer described by Maxwell-Boltzmann distributions, but require explicit Collisional-Radiative Models (CRM).

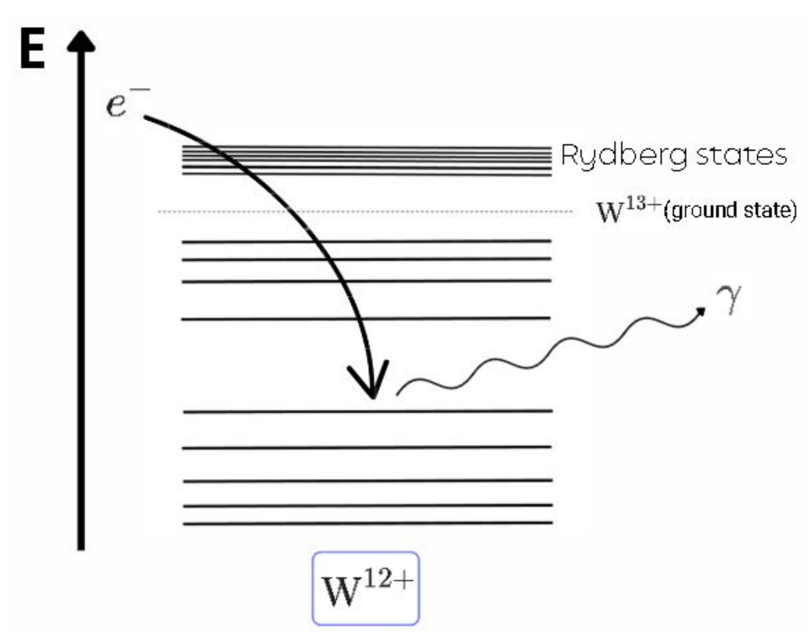
Such models depend heavily on accurate atomic rates, specifically **Radiative (RR)** and **Dielectronic Recombination (DR)** [1,2]. As experimental data remains insufficient, theoretical calculations are essential to bridge this gap and correctly model spectral signatures.

W XIV BENCHMARK

We employ the fully relativistic Distorted Wave method using FAC [3]. Pm-like Tungsten (W XIV) is selected as a benchmark because:

- It mimics the complex open f-shell structure of key r-process elements [4].
- It offers a wealth of reference data [5,6] for validation.

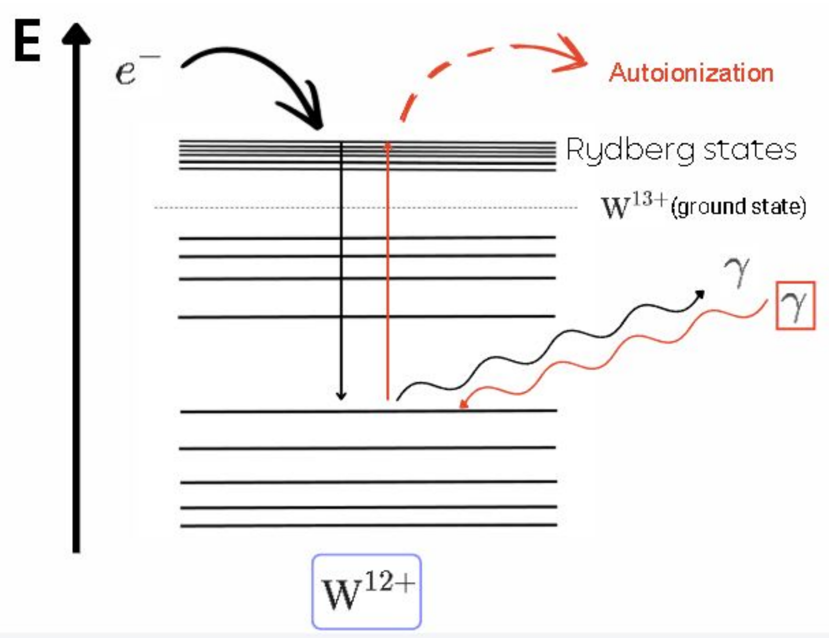
RR & DR Scheme



$$e^- + W^{13+} \longrightarrow W^{12+} + \gamma$$

RR: Direct, non-resonant capture of a free electron into a bound state, emitting a photon.

The photon carries the capture energy plus the electron's kinetic energy, resulting in a continuum process.

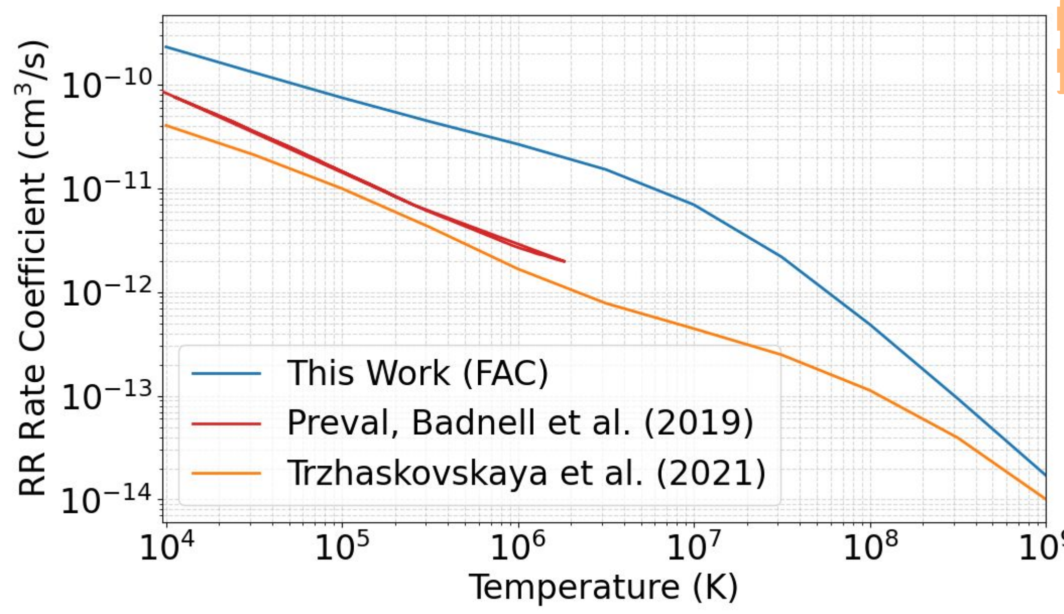


$$e^- + W^{13+} \longrightarrow (W^{12+})^{**} \longrightarrow W^{12+} + \gamma$$

DR: A two-step resonant process: electron capture excites a core electron to form a doubly excited state, which then stabilizes via radiative decay.

We calculate the rates of **autoionization,** and, via detailed balance we retrieve its inverse counterpart DR Rates.

RR RATES

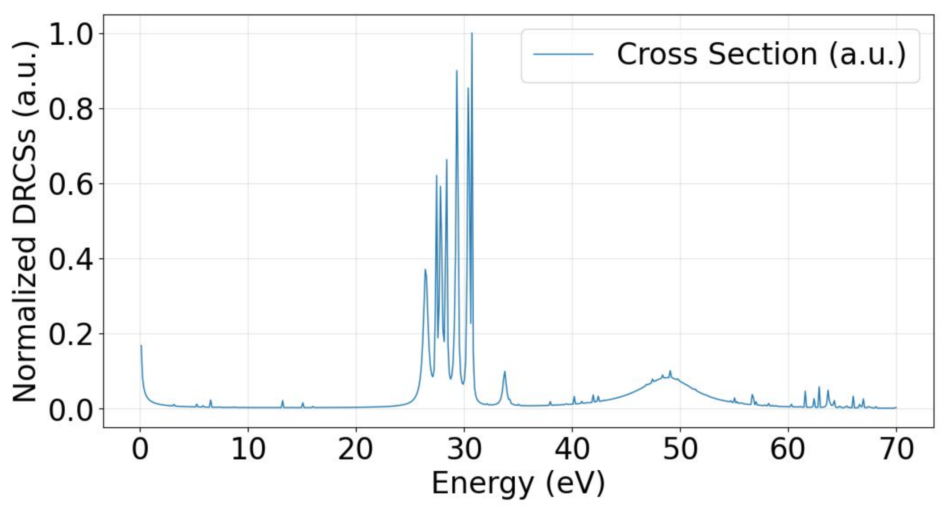


W XIV Target

$4f^{13}5s^2$
$4f^{12}5s^25p$
$4f^{11}5s^25p^2$
$4f^{14}5s$
$4f^{13}5s5p$
$4f^{12}5s5p^2$
$4f^{10}5s^25p^3$
$4f^{14}5p$
$4f^{11}5s5p^3$
$4f^{12}5s^25d$

Our data exceed previous works, likely due to the inclusion of the contributions from additional channels up to 380 eV.

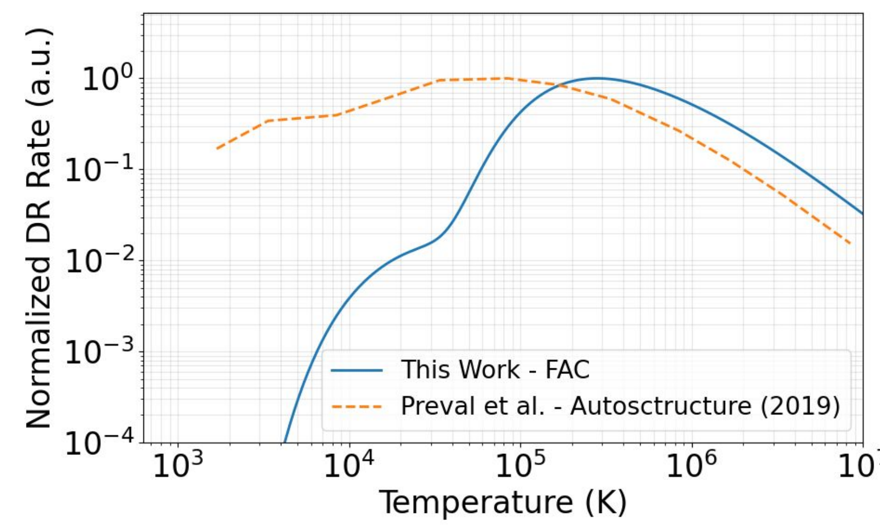
DR RESONANCES and RATES



Peak resonant states

C1: $4d^94f^{14}5s^25d^1$
C2: $4d^94f^{13}5s^25p^15d^1$
C3: $4d^94f^{14}5s^26s^1$
C4: $4d^94f^{13}5s^25p^2$
C5: $4d^94f^{13}5s^25p^16s^1$

Conf.	E_{kin} (eV)	S (Mb·eV)
C1	48.92	2.60×10^3
C2	63.71	8.13×10^0
C3	64.22	1.64×10^0
C4	5.99	4.92×10^0
C5	69.94	9.05×10^{-2}



The strengths (table) show that our preliminary results are dominated by the 4d to 5d core excitation at 48.9 eV. This resonant state dwarfs the low-energy contributions (e.g., at 5.99 eV), which are 500 times weaker. This explains the peak shift towards higher temperatures and the underestimation in the low-temperature region, suggesting the importance of low-energy valence transitions in DR rates.

CONCLUSION

This work reveals the importance of recombination channels previously overlooked, particularly higher order excitations. Their inclusion is expected to have a considerable influence on the accurate modeling of Lanthanide opacities in Kilonovae ejecta.

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